Red-Water Blooms off Northern Chile, April–May 1956, with Reference to the Ecology of the Swordfish and the Striped Marlin[1]

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From mid-April to early May 1956 the writer participated in the University of Miami–Lou Marron Pacific Billfish Expedition off northern Chile in the Peru Coastal Current (Sverdrup et al., 1942: 701–702). During this period, water temperatures and plankton tows were taken, and observations were made on the biology and distribution of several planktonic and nektonic species.

The data accumulated suggest that certain hydrographic features of the region favor the establishment of a food web beginning with phytoplankton blooms and culminating with the concentration of broadbill swordfish, *Xiphias gladius* Linnaeus, and striped marlin, *Tetrapturus audax* Philippi.

METHODS AND MATERIALS

From Apr 18 to May 10, cruises were made from Iquique on several vessels. Although the primary purpose of these cruises was to capture swordfish and marlin, the cruises were planned to permit temperature transects to be made along the coast, and to deduce therefrom, in the absence of salinity data, a pattern of surface currents and their ecological effects upon marine organisms. A bucket thermometer was used to take a total of 182 surface temperatures over a 1-week period, and 22 bathythermograph casts up to 180 m were made on May 2.

Approximate locations at sea were determined on nautical charts by running time and by the use of landmarks. Because of the conspicuous peaks of the Andes foothills, it was usually possible to locate the positions reasonably well, but these are only approximate positions.

On several of the cruises, surface plankton tows were made with a 1-m, size 00 mesh, nylon plankton net, and collections were preserved in 5% formalin. These were deposited at the Institute of Marine Science, University of Miami.

A running log was kept on hydrographic, meteorological, and biological information. These data included water and air temperatures; wind, sea, and other pertinent data; occurrence of swordfish, striped marlin, squids, bonito, anchovies, and plankton concentrations. Original hydrographic data were deposited with the U. S. Navy Hydrographic Office as "Cruise 1366, R/V *Genie* II." The writer's data have been markedly supplemented by Mr. and Mrs. John A. Manning's logbook on the biological aspects. In addition, some information was available from local fishermen on the occurrence of swordfish and marlin, as well as on the stomach contents of swordfish.

HISTORICAL BACKGROUND

The sea off Chile and particularly off Peru has been studied for many years. Sears (1954) has summarized much of the pertinent literature on hydrography. Other papers on hydrography include Dall (1909), Bini (1952), de Buen (1957), and Posner (1957). Plankton blooms have been noted by Murphy (1926) and Gunther (1936*a*), and fish mortality by Cienfugos (1895), Coker (1910), Lavalle (1917*a,b,* 1924), Rahm (1937), Falke (1939, 1950), Brongersma-Sanders (1948, 1957), and Schwabe (1951). The distribution and mortality of squids is covered by d'Orbigny (1835–43), Hupe (in Gay, 1854), Pfeffer (1912), Schneider (1930); pelagic fishes are discussed by Bini (1952), Mann (1954), University of Miami (1955), de Buen (1957), and Manning (1957). A number of these authors have discussed the interesting phenomenon and consequences of the junction

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of the cold Peru Current (*sensu lato*) with that of the Equatorial Counter Current which occasionally results in the mass death of organisms. Hydrographic information indicates that the mortality off Peru may be due essentially to the junction of warm and cold waters resulting in traumatic death for many organisms due to the sudden temperature change (Posner, 1957). Sears (1954) pointed out that upwelling and surface warming off Peru may also result in phytoplankton blooms and death of organisms, the red water there being known as "aguaje." The causes of the two types of catastrophes are evidently distinct, although the results are similar. Red water also occurred in a transitional zone observed during the present study between southern Peru and northern Chile, at approximately 20° S. Here, tongues of warm water from the north are apparently restricted to the shallow surface layers (Bini, 1952). The result of this juncture is the production of red water, and the subsequent concentration of several organisms.

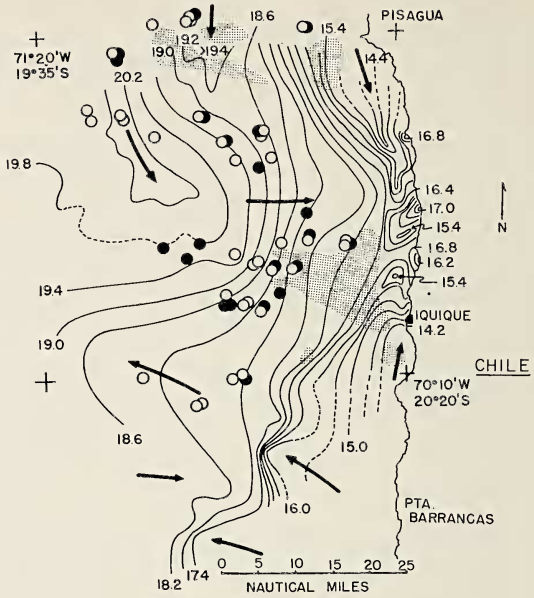

FIG. 1. Distribution of red-water patches (stippled area), swordfish (open circles), and striped marlin (closed circles) in relation to surface water temperatures (° C) off northern Chile, Apr–May 1956. Arrows represent probable surface currents. Isotherms are contoured every 0.4 C.

TEMPERATURE DATA

Only limited environmental information is available from a quasi-synoptic pattern of surface temperatures (Fig. 1). Since temperatures were taken over a period of 1 week, the data must be viewed with reservations. Sears (1954) doubted the reliability of surface temperatures for interpreting hydrographic conditions where solar heating is appreciable. However, the prevalence of a persistent cloud cover during the period of study would seem to preclude any extensive surface heating (U.S. Navy Hydrographic Office, 1938).

Tongues of warm water flowing from the north are juxtaposed with northward-flowing cooler waters from the Peru Coastal Current. Earlier studies (University of Miami, 1955) suggest that the front, a junction of the colder and warmer waters, moves north later in the year. Gunther (1936*a*,*b*), Bini (1952), and Posner (1957) showed that a warm lens off Peru may flow from the offshore anticyclonic eddy. As evidenced by the bathythermograph data taken in the present study, these lenses (Figs. 2–4) are thin and stratified, overlying the colder Peru Coastal Current water from the south, with little mixing probably occurring except by diffusion processes. There is some indication from vertical profiles and thermocline depth (University of Miami, 1955) that to the north some onshore movement of water occurs.

No bathythermograph casts were made close to shore, but upwelling of cool subsurface waters is evident in the surface temperatures (Fig. 1), and a cool southward-flowing tongue is advected coastwise from Pisagua. The prevailing southeast trade winds which are strongly developed during the winter are responsible for this upwelling (Wooster, 1959). Gunther (1936*b*) pointed out that in these waters upwelling occurs between 40 and 360 m, yet there is no indication that any of these nutrient-rich waters are carried into the relatively impoverished photic zone.

Close to and parallel with a weak divergence region, a relatively wide convergence region is seen between the cooler coastal water and the warm advected tongues from the north. Data taken by Mr. and Mrs. Manning in late May

suggest that this convergence region may move northerly as winter approaches (see Wooster, 1959, for data on the Peru Current). Similarly, it would be expected to migrate southward with the advent of warmer temperatures from the north.

NUTRIENTS

Posner (1957) showed that during his study the surface waters of the Peru Current were rather nutrient-poor, at least in the latitudes from 3° to 14° 30′ S, and it is seen that surface waters from the north extend well into the Iquique area (Fig. 1). There is no information available to me on the amount, source, or distribution of nutrients in the Peru Current off Chile. Upwelling of nutrient-rich deep waters into the photic zone, leaching of nitrate and guano deposits from the coastal region, excreta from guano birds, and the decomposition of squids of the plankton blooms, may contribute to the production. Mortality of squids off Chile is a well-known annual event which was first noted by d'Orbigny (1835–43) and was subsequently described by Schneider (1930), Schwabe (1951), and Wilhelm (1930, 1932, 1954). The death of squids appears to be connected with the reproductive cycle and the termination of spawning (see McGowan, 1954). The possibility of a nutrient supply from decomposing animals for "red tides" off the Florida west coast has been discussed by Ingle and de Sylva (1955). Clearly, the nutrient cycle in Chilean waters needs intensive study, but for the purposes of the present discussion it must suffice to say that nutrients must have been plentiful during the period of red-water blooms.

RED-WATER BLOOMS

During the observations made in Apr and May, the dominant phytoplankton organism in red-water patches (Fig. 1) was identified by the writer as *Prorocentrum micans* Ehrenberg. This organism had reached bloom proportions by late Apr, coloring the water a deep rusty red. Interspersed with this dinoflagellate were unidentified globigerines and ciliates. The concentration of *Prorocentrum* in a red-water patch off Iquique on Apr 28, 1960 was esti-

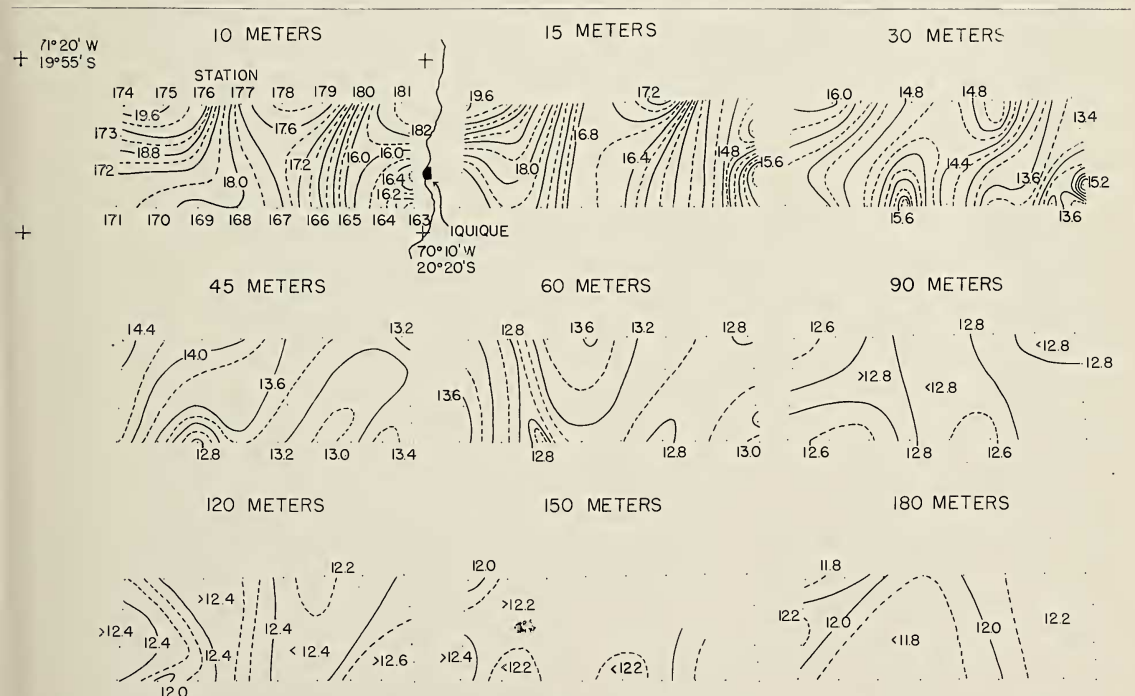

FIG. 2. Distribution of temperature (° C) off Iquique, Chile, on May 2, 1956, at various depths, based on bathythermograph readings. Isotherms are contoured every 0.4 C.

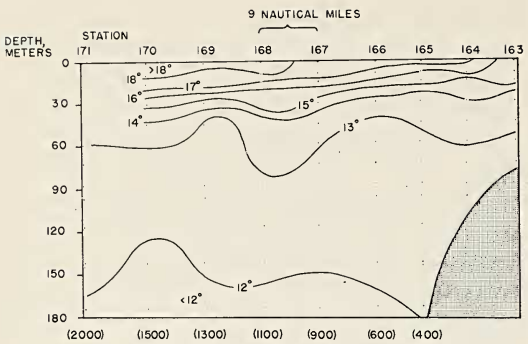

FIG. 3. Transect south of Iquique, Chile, at approximately 20° 18′ S, on May 2, 1956, based on bathythermograph readings. Isotherms are contoured every 1.0 C. Figures in parentheses are depths. (See Fig. 2 for station plan.)

mated to be 20,000 per 1. During late Apr and early May the phytoplankton patches were distributed relatively close to shore in the convergence areas, parallel to shore. These patches occurred along junctures of warm offshore waters and cooler coastal waters. The red water during early May was found only along this juncture. However, by mid and late May red water had extended to 60 miles offshore (Mrs. John A. Manning, *in litt.*). The red-water patches were found along convergence lines rather than in upwelled areas close to shore, and at the time the studies were made they were seldom found in blue, blue-green, or white water, but were found in the dirty green water characteristic of the inshore areas.

The occurrence of red-water conditions was associated in early May with the appearance of a few dying cormorants and an occasional dead or dying fish at the surface. However, by late May angling was reportedly poorer in the Iquique area, and many dead cormorants, shearwaters, and other birds were seen in the red-water patches close to shore and even offshore. On May 27, Mrs. Manning observed dead birds 45–50 miles offshore. Concurrent with the appearance of sick and dead birds in the area, it was noted that the birds which formerly fed actively on the schools of surface-swimming fish were reluctant to feed despite the presence of schools of anchovies in red water. Additional information on the extent of red water is given by Manning (1957).

It is not certain if the populations of *P. micans* were advected from the north into the nutrient-rich waters of the south, or whether the nutrient-laden (i.e., guano) waters from the north were inoculated by phytoplankton from the south. Since this is a coastal species which also causes red-water conditions off southern California (Brongersma-Sanders, 1957: 980), its zoogeographical affinities would be more nearly with those of the Eastern Tropical Pacific than with the waters of the cool Southeast Pacific. A chart given by Brongersma-Sanders (op. cit.: 952, fig. 4) shows that red-water blooms in the eastern part of the Pacific Ocean are limited essentially to tropical waters. Thus it seems more likely that the source of *P. micans* was from northern waters.

ZOOPLANKTON

Numerous tows were made with a 1-m plankton net in the surface waters off Iquique. The dominant organisms were euphausiids, zoea, copepods, and, at times, an unidentified scyphozoan, similar in appearance to *Linuche.* Cursory examination of the guts of the euphausiids and copepods in the field showed red pigmentation. Although subsequent microscopic examination in the laboratory did not reveal identifiable dinoflagellates, the red pigment was assumed to have originated from organisms in the surrounding water, since concentrations of the reddish dinoflagellates were observed at the same time the tows were made. The zooplankton concentrations were especially heavy early in the morning and toward dusk, although copepods tended to be somewhat more numerous in the twilight hours than at dusk. While much work is needed on this subject, it is suggested that zooplankton had grazed extensively on the populations of *Prorocentrum.*

ANCHOVIES

The distribution of the anchovy, *Engraulis ringens* Jenyns, coincided closely with that of the red-water patches (Fig. 1). A few anchovies were seen offshore, but they were most common in the red-water patches at the juncture of the cold and warmer waters. The anchovies apparently were not affected by the red water; at least no sick or dying specimens were observed.

Although no fresh anchovies were captured by us during this study, Rojas (1953) found that the stomachs of anchovies taken off Peru contained diatoms, dinoflagellates, and zooplankton. By far the greatest proportion was diatoms, while dinoflagellates and zooplankton were relatively less important in the stomach contents. Rojas postulated a preference by anchovies for diatoms, although this would seem to relate more to availability, particularly since in the accompanying data the relative abundance in plankton nets corresponded closely with the kinds found in the stomachs.

Anchovies are fed upon by pelicans, cormorants, shearwaters, and petrels, and subsequently these species were observed dead and dying along the coast.

SQUIDS

The giant squid or jibia, *Dosidicus gigas* (d'Orbigny), occurred throughout the region of study, that is, both in the inshore green water and in the offshore blue water, but it seemed more abundant close to shore. It also occurred farther north at the junction of the warm and cool waters. At night it could be taken on hook and line from 7 to 10 m in depth, where it seemed common. Giant squid were often observed by us while trolling our baits. A smaller squid, *Loligo gahi* d'Orbigny, is more of an inshore species than *Dosidicus gigas.* A number of these small forms were taken from bonito stomachs and they in turn contained unidentifiable fragments of fish flesh. Specimens of *D. gigas* were dissected; of eight freshly caught individuals examined two were empty; three stomachs contained fragments of anchovies; one stomach contained a saury, *Scomberesox equirostrum* LeSueur; and two stomachs contained squid flesh. Rahm (1937) obtained plankton and fish remains from squid off the southern Peruvian coast; Wilhelm (1954), in examining specimens of *Dosidicus gigas,* found numerous crustaceans, as well as hake, *Merluccius gayi* (Guichenot), and small individuals of *Dosidicus gigas.*

Dr. Gilbert L. Voss (*in litt.*) states that there is another genus and species of ommastrephid squid found commonly in these waters which is confused with *D. gigas.* Thus, definite identification of the smaller squids must await a thorough taxonomic study of the cephalopods of that area.

Kojima (1959) inferred that in Japanese waters squid, *Ommastrephes sloani pacificus* (= *Todarodes pacificus*), diurnally undergo a vertical migration, emerging from the depths in the early evening and descending at dawn. He further pointed out that following this migration a passive "migratory" drift resulted in concentration of squid. If such a drift does occur off Chile then one might expect to find concentrations of either species of squid in convergence areas, thus making them more available to predatory fishes.

BONITO

Bonito, *Sarda chilensis* (Cuvier), are very abundant in the coastal green waters off Iquique, where they are fished commercially with purse seines. Like the anchovy, they were usually found in the dirty or red-water patches. Thirty bonito were caught on hook and line and their stomachs examined. Of these, 7 appeared to have recently regurgitated their food; 13 contained squid flesh, eyeballs, or beaks; 2 contained fish flesh; 8 had fish vertebrae, probably from clupeoids. All bonito were taken close to shore amid schools of anchovies and plankton swarms. The small squid in the bonito stomachs could not be positively identified but they appeared to be *Loligo gahi.*

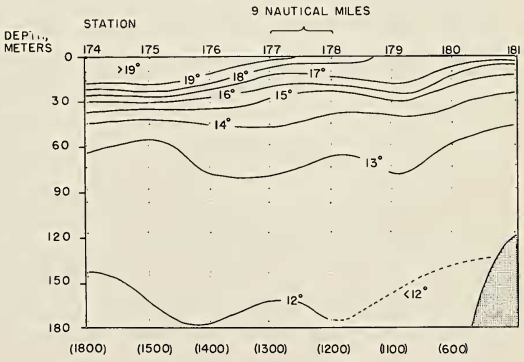

FIG. 4. Transect north of Iquique, Chile, at approximately 20° 05′ S, on May 2, 1956, based on bathythermograph readings. Isotherms are contoured every 1.0 C. Figures in parentheses are depths. (See Fig. 2 for station plan.)

TABLE 1

FREQUENCY DISTRIBUTION OF SURFACE WATER TEMPERATURES (° C) IN WHICH SWORDFISH AND STRIPED MARLIN WERE OBSERVED IN WATERS OFF NORTHERN CHILE FROM APR 8 TO MAY 28, 1956

TEMPERATURE (° C)	SWORDFISH					STRIPED MARLIN				
	Apr	Apr	May	May	Total	Apr	Apr	May	May	Total
	8–18	23–30	2–12	22–28		8–18	23–30	2–12	22–28	
17.4				1	1					
17.6							1			1
17.8				1	1					
18.0				2	2				1	1
18.2								1		1
18.4										
18.6		1		1	2					
18.8		2	2		4		1	4	1	6
19.0		4	7		11		1	5		6
19.2			8		8			3		3
19.4			3		3		3	4		7
19.6		2	2		4			1		1
19.8			1		1		3			3
20.0	2	2	2		6		1			1
20.2		1			1		2			2
20.4	2	2			4					
20.6	1	1			2	1				1
Mean temperature					19.3					19.2

SWORDFISH AND MARLIN

Swordfish were observed or caught where the warmer eddies from offshore and to the north were adjacent to the colder waters of the Peru Coastal Current from the south (Fig. 1). Generally they were taken in clear blue or white water above 18.8 C, with the greater numbers occurring in the warmer waters. There was a distinct tendency, over a 6-week period in Apr and May, for the swordfish to follow the retreating marine "warm front" to the north (see Manning, 1957), which also seemed to present a front for squids. This front left in its wake large patches of red water, at the edge of which the swordfish occurred. Swordfish occurred in only somewhat warmer water than did striped marlin (Table 1), which often were seen at the edge of but seldom in the red-water patches, as well as in the white or blue water.

Seven female swordfish were examined. In the five which contained food, 24 squid (*Dosidicus*) were found. Although no bonito were observed, the natives reported that bonito are eaten by swordfish, and occasionally by marlin. LaMonte (1955) noted that striped marlin off Chile and Peru contained only squid, and LaMonte and Marcy (1941) reported that they always found partially digested squid in the stomachs of marlin and swordfish. Stomach contents of marlin and swordfish examined during the present study suggest that most feeding occurs near the surface. Off southern California, however, Mr. Robert L. Wisner (*in litt.*) reports that the stomach contents of swordfish indicate that they feed on rather deepwater fishes.

During the present study, three striped marlin, all females, were examined; all contained food. One had eaten squid and anchovies; the second contained 42 anchovies and three scads, *Trachurus symmetricus murphyi* Nichols; and the third contained an undetermined number of anchovies and one saury. In southern California waters, Hubbs and Wisner (1953) found that the saury, *Cololabis saira* (Brevoort), was the most important item in the stomachs of striped marlin, with anchovy, *Engraulis mordax* (Girard), being of considerable importance. They

attributed the apparent importance of sauries merely to their abundance in the offshore areas in which the marlin had been feeding.

CONCLUSIONS

It is suggested that hydrographic conditions during the present study off Iquique resulted in an influx of a thin warm-water layer from the north containing dinoflagellate populations; an admixture of nutrients, derived at least in part from upwelled coastal water from the south, caused growth of the dinoflagellate population, which resulted in a concentration of the zooplankton crop. Subsequently, anchovies concentrated and fed in these plankton patches and they in turn attracted squid and bonito. Swordfish and striped marlin moved into this region apparently attracted by the concentrations of squids as well as of anchovies. However, they were also probably affected by decreasing water temperatures, as this concentration seemed to be part of a northerly migration toward the onset of winter, following the northward-retreating warm front. It was reported that by late May, most swordfish were being taken well north of the Iquique area toward Arica. This exodus may have been further prompted by the growth in area (to 60 miles offshore) of reported red-water conditions unfavorable to swordfish.

ACKNOWLEDGMENTS

I wish to express my sincere appreciation to Mr. and Mrs. John A. Manning for furnishing data from their cruises off northern Chile, for the use of their boat and equipment, for their many worthwhile suggestions, and for constant encouragement during my stay in Chile. Thanks are due Mr. and Mrs. Lou Marron for the use of their boat and for financial support of the expedition which permitted the scientific aspects to be carried out. Appreciation is expressed to Captain Walter H. Gorman and Mr. James Lynch for field assistance, and to Mr. Albert van der Riet for observations on the distribution of swordfish and marlin. Field work would have been impossible without the able assistance and advice of the Chilean boat crews. Thanks are also due Mr. Syres Dawson of Grace y Cía for the use of shore-based facilities, and to Mr. Armando Huerta and his staff at the Hotel Prat, Iquique, for their kind cooperation in supplying the needed space and equipment. Drs. F. G. Walton Smith and Gilbert L. Voss of the Institute of Marine Science, University of Miami, supplied valuable information on the planning of the expedition, and their criticisms and suggestions toward the improvement of the manuscript were supplemented by those of Drs. F. F. Koczy, H. B. Moore, and C. R. Robins.

SUMMARY

1) Surface temperatures and bathythermograph readings were taken, and observations on the distribution of several marine organisms were made in Apr and May 1956 over a relatively small area north and south of Iquique, Chile, and seaward to about 60 nautical miles in the Peru Coastal Current.

2) The area is characterized by a narrow continental shelf with deep water close to shore and complex coastal currents, with a drift of warm water from the north superimposed upon upwelled cool water.

3) Admixture of these two bodies of water appeared to favor the growth of dinoflagellates ("aguaje"), which in turn supported a food web of copepods, zoea, euphausiid shrimp, anchovies, bonito, and squids.

4) The concentrations of squids, bonito, and anchovies, as foods of swordfish and marlin, are thought to be an indirect result of the productivity caused by the juncture of the two currents.

5) The distribution of the swordfish and marlin in northern Chile, based on personal sightings and records from fishermen, is discussed in relation to ecological conditions.

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